

DNA MICRO-ARRAY HAVING STANDARD PROBE AND KIT  
INCLUDING THE ARRAY

This application is a continuation of

5 International Application No. PCT/JP03/07918 filed on June 23, 2003, which claims the benefit of Japanese Patent Applications No. 2002-183249 filed on June 24, 2002 and No. 2002-191390 filed on June 28, 2002.

10 BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a DNA micro-array useful for quantitative analysis of a target nucleic acid (target nucleic acid hereinafter) in a sample. More specifically, the present invention relates to a DNA micro-array that can improve accuracy in a quantitative analysis using a DNA micro-array of nucleic acid probes having a sequence expected to be complementary to a target nucleic acid 15 sequence in a sample. The present invention also relates to a detection kit using the DNA micro-array.

20 Related Background Art

As a result of development in methods for detecting and measuring genetic DNA on the basis of 25 hybridization process, rapid progress has been made in studies of gene chip (DNA chip, micro-array) where a plurality of nucleic acid probes are immobilized on

a substrate, allowing multiple detection tests on genetic DNA in a sample concomitantly. The method of detecting and measuring genetic DNA contained in a sample using a gene chip (DNA chip, micro-array) is  
5 expected to be applied in various fields such as molecular biological researches, and gene disorder and infectious disease diagnoses.

The basic form of a gene chip is that a plurality of single-stranded nucleic acid fragments  
10 expected to have a complementary base sequence to the base sequence of a target gene are arranged in an array and immobilized on the surface of a substrate such as a glass substrate in order to detect target genetic DNA by the hybridization process. Single-  
15 stranded nucleic acid fragment to be used as a probe having a complementary base sequence to a target gene can be a chemically synthesized DNA oligomer called "oligo-DNA" or a complementary strand DNA fragment called "cDNA" enzymatically synthesized using a gene  
20 derived from a biomaterial as a template. As for immobilization of oligo-DNA on the surface of the substrate, methods are roughly classified into two: one is, as shown in US 5,474,796 B (or JP 9-500568 A, ProtoGene Laboratories), to synthesize DNA molecules  
25 on the substrate sequentially after immobilizing one end to the substrate, the other is, as disclosed in JP H11-187900 A (Canon), oligo-DNA are synthesized,

and then various bonding means are used to immobilize these nucleic acid fragments on a substrate. As described above, the immobilizing method is roughly classified into above two methods.

5       As the means for immobilizing the separately prepared nucleic acid fragments on the substrate, various methods have been proposed, such as an adsorption immobilizing method making use of the charge of a substrate and the charge of a nucleic  
10      acid fragment, and an immobilizing method which is aimed to improve immobilization efficiency by using a coating film formed by coating the substrate surface with a poly-L-lysine or amino silane coupling agent.

Currently, DNA micro-arrays are not provided  
15      with special probes for quantitative analysis of nucleic acid having a target sequence (target nucleic acid). Whether the DNA micro-array is a DNA micro-array formed on the surface of a solid phase by a sequential synthesis method or a DNA micro-array  
20      produced by a pin method, there are variations caused by the production process, for example, variation in synthesis efficiency due to the nucleic acid sequence, variation in the amount of the probe liquid dropped from a pin spotter on a substrate or variation in  
25      immobilization rate. Therefore, there are problems in quantification accuracy and reproducibility. An ink jet production method has been proposed (JP H11-

187900 A) to solve the variation at the time of DNA micro-array production.

On the other hand, a sample to be examined by the DNA micro-array is subjected to an amplification operation to amplify a target nucleic acid from the viewpoint of sensitivity, as well as to incorporate a detectable label to into the amplified product. The basic technology of this amplifying operation is called "PCR" and disclosed in US 4683195 B, US 10 4683202 B and US 4965188 B. However, PCR involves hard-to-control factors in the amplification reaction process. For example, it is well known that even when the same samples are amplified at the same time, the amplification yield may differ by several times 15 to several tens of times. Studies have been made to solve this uncertainty in the amplification yield, providing competitive PCR etc. The competitive PCR is detailed in reports by P.D. Siebert et al. (Nature 359; 557-558 (1992), Bio Techniques 14; 244-249 20 (1993)). As an alternative method, a known amount of a certain nucleic acid is added as an internal standard to a sample taken from a patient, and the internal standard nucleic acid and the target nucleic acid are amplified in order to estimate the 25 amplification rate of the target nucleic acid from the amplification rate of the internal standard nucleic acid.

#### SUMMARY OF THE INVENTION

As described above, when a quantitative analysis of a target nucleic acid is carried out using a DNA micro-array, there exist various unstable 5 factors that affect the determination.

First of all, there is low reliability of accuracy and reproducibility due to variation in the amount of a probe immobilized on a substrate during production of a DNA micro-array. There is also 10 variation in the amplification rate of a target nucleic acid in a sample due to the uncertainty of the amplification efficiency of the target nucleic acid in PCR. Conventionally, variations in these different factors are calibrated by various methods 15 separately, and then quantitative analysis is carried out using a DNA micro-array, and the analytical data are corrected on the basis of the calibration results for quantitative determination.

Since these calibration procedures are very 20 complicated and time-consuming, they are inhibiting factors in processing a large number of samples.

The present invention is to solve the above problems. It is therefore an object of the present invention to provide a DNA micro-array which allows 25 obtainment of correction data at the time of quantitative determination of the amount of a target nucleic acid in a sample, greatly simplifying the

calibration procedures, as well as an assay kit used for the above purpose.

The inventors of the present invention have studied intensively to solve the above problems and  
5 have found that these assay works can be greatly simplified if a DNA micro-array is prepared by applying and immobilizing separately prepared nucleic acid probes using an ink-jet method (JP H11-187900 A) and at least either a probe for an internal standard  
10 nucleic acid (internal standard probe hereinafter) or a probe for an external standard nucleic acid (external standard probe hereinafter) is immobilized together with the nucleic acid probes for detecting target nucleic acid. Based on the above findings,  
15 the inventors of the present invention have also devised a kit for carrying out these assay works using the above DNA micro-array accurately and easily to complete the present invention.

Thus, according to the present invention, there  
20 is provided A DNA micro-array for detecting nucleic acid molecules having target base sequences in a sample comprising a substrate and nucleic acid probes having base sequences substantially complementary to the target base sequences immobilized on the  
25 substrate, wherein the array contains additional probes of one or several kinds selected from the following probes:

probes for internal standard nucleic acids (internal standard probes) of one or several kinds which hybridize with said internal standards and are added for quantitative evaluation of PCR of said nucleic acid molecules having the target base sequences;

5 probes for external standard nucleic acids (external standard probes) of one or several kinds which hybridize with said external standards and are added for evaluation of accuracy of detection operation

10 and for quantitative analysis of the amount of the probes having base sequences substantially complementary to the target base sequences;

15 and probes added for quantitative evaluation of the amount or density of said nucleic acid probes having base sequences substantially complementary to the target base sequences, which are immobilized by the same method as said nucleic acid probes.

Preferably, probes for internal standard nucleic acids and probes for external standard nucleic acids is immobilized on the substrate at four probe concentrations or densities to form a group.

Preferably, the internal standard probe to be immobilized on the DNA micro-array comprises at least two kinds of probes corresponding to amplification products of two different chain lengths obtained from the internal standard nucleic acid. Also the external standard probe comprises preferably at least

two kinds of probes of an appropriate base number being complementary to the external standard nucleic acid to be added.

More preferably, the internal standard probe  
5 and the external standard probe are synthetic nucleic acids immobilized on the substrate. The chain length of the synthetic nucleic acid is 15 to 75 bases preferably.

Further, when the DNA micro-array according to  
10 the present invention contains an internal standard probe, an internal standard nucleic acid is amplified together with the target nucleic acid in one amplification reaction to determine the amplification efficiency of the reaction. The present invention  
15 also provides a primer set for an amplification reaction of an internal standard nucleic acid. That is, the primer set of the present invention is for amplification of an internal standard nucleic acid to be amplified together with a target nucleic acid and  
20 is designed to generate an amplified product having a chain length similar to the amplification product of the target nucleic acid.

The present invention also provides a detection kit suitable for quantitative detection of a target  
25 nucleic acid using a DNA micro-array of the present invention, which includes a primer set for the amplification reaction of the internal standard

nucleic acid to be amplified together with the target nucleic acid. When the amplification product of the target nucleic acid is of two or more chain lengths, the kit includes at least two primer sets as claimed 5 in claim 7, corresponding to the chain lengths. The primer sets include at least one primer set to obtain an amplification product of 200 bp or less in chain length, at least one primer set for an amplified products of 200 to 500 bp, at least one primer set 10 for 500 to a 2,000 bp amplification product, and at least one primer set for a 2,000 bp or more amplification product.

Preferably, according to the present invention, a kit for detecting a target base sequence includes 15 internal standard nucleic acid to be amplified together with a target nucleic acid in an amplification reaction for quantitative detection of a target nucleic acid using the DNA micro-array, where the internal standard nucleic acid is two or 20 more nucleic acids derived from a microorganism or a virus having no homology with the target base sequence to be detected.

The present invention also provides a detection kit containing external standard nucleic acid, 25 suitably used for the quantitative detection of a target nucleic acid using the DNA micro-array of the present invention containing external standard probes.

That is, according to the present invention, there is provided a kit for detecting a target base sequence, including at least two external standard nucleic acids to be added to a sample upon quantitatively 5 detecting a target nucleic acid using a DNA micro-array, where the external standard nucleic acids are synthetic nucleic acids labeled with a detectable marker. The marker is preferably a fluorescent material, a radioactive material or a luminescent 10 material.

In the DNA micro-array of the present invention, the nucleic acid probe includes a single-stranded nucleic acid, specifically DNA, RNA, PNA (peptide nucleic acid), cDNA (complementary DNA) or cRNA 15 (complementary RNA). Further, the DNA micro-array may comprise a single-stranded nucleic acid as a nucleic acid probe and a target nucleic acid hybridized to the nucleic acid probe.

20 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows an internal standard probe, external standard probe, external standard nucleic acid and internal standard nucleic acid, a primer set for amplification of an internal standard nucleic 25 acid and amplified products thereof according to an embodiment of the present invention;

Fig. 2 schematically shows an arrangement of

internal standard probes in the DNA micro-array according to an embodiment of the present invention;

Fig. 3 is a graph showing calibration curves for calculating the probe immobilization rate using 5 external standard probes in the DNA micro-array in quantitative analysis using the DNA micro-array according to the present invention;

Fig. 4 is a graph showing calibration curves for calculating the PCR amplification factor using 10 internal standard probes provided in the DNA micro-array in quantitative analysis using the DNA micro-array according to the present invention, the graph also showing a difference in detection sensitivity according to the chain length of the nucleic acid of 15 the amplified product;

Fig. 5 schematically shows the plane arrangement and sectional form (taken along the line A-A) of a biochip as a structural example according to the present invention; and

20 Fig. 6 is a graph showing the relationship between the measured secondary ion intensity and DNA formation density (number of DNA molecules per probe dot) of a biochip.

25 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

According to a first aspect of the present invention, there is provided a DNA micro-array having

an internal standard probe formed thereon.

In a broader sense, the internal standard probe is a probe for detecting an internal standard nucleic acid to be used to assist quantitative determination 5 of a target nucleic acid. This probe is a nucleic acid probe having a base sequence complementary to an internal standard nucleic acid or gene of which amount in a sample is known and can bind to it, to enable quantitative determination of a target nucleic 10 acid on the basis of the relative ratio of the internal standard nucleic acid to the target nucleic acid bound to the array. For example, a transcription product of a gene encoding a cytoskeleton (a house keeping gene) is often used as 15 the internal standard nucleic acid because its expression amount hardly changes and is relatively large. Specific examples of the transcription product include mRNA of GAPDH or of  $\beta$ -actin and ribosomal RNA.

20 In a narrower sense, the internal standard is a nucleic acid of a known base sequence to be added in a sample in a known amount when an amplification reaction of nucleic acid (e.g., PCR) is carried to increase the amount of nucleic acid or to label the 25 target nucleic acid with a detectable marker. Such an internal standard nucleic acid to be added to the sample is selected so as to be amplified or labeled

at the same efficiency as the target nucleic acid when amplification or labeling of the target nucleic acid is carried out. After the amplification or labeling reaction, the amount of the internal standard nucleic acid is determined to calculate the amplification factor or labeling rate so that the amount of the target nucleic acid can be obtained as a relative value based on the amount of the internal standard nucleic acid.

According to a second aspect of the present invention, there is provided a DNA micro-array having a probe for an external standard nucleic acid (external standard probe) formed thereon.

Here, the external standard nucleic acid is a nucleic acid having a known base sequence to be added to a sample in order to compensate variation in the DNA micro-array production step and/or in the detection and measurement step. More specifically, it is a nucleic acid prepared by introducing a detectable and determinable marker into a highly purified nucleic acid such as synthesized DNA or plasmid DNA, of which labeling rate etc. are determined in advance. This external standard nucleic acid may be used for any type of DNA micro-arrays not depending to the type of target genes so long as it has no base sequence homology to the base sequence of the target nucleic acid. The external

standard probe is a nucleic acid probe having a base sequence complementary to the external standard nucleic acid and can selectively bind to the external standard.

5       Plural sets of external standard nucleic acids and external standard probes may be used at the same time to determine the performance of the DNA microarray, that is, quantification ability thereof. More specifically, a DNA micro-array having not less than  
10 three, preferably not less than five external standard probes is prepared, and labeled external standard nucleic acids corresponding to these probes are added in known but different amounts when the target nucleic acid is detected. Calibration curves  
15 can be prepared by plotting the detected and added amounts of these external standard nucleic acids. The amount of a probe immobilized on a DNA microarray can also be corrected by using a set of external standard nucleic acid and external standard probe. That is, variation in probe immobilization efficiency between DNA micro-arrays (substrates) can be corrected using such a set. In this method, an external standard probe is immobilized on a DNA  
20 micro-array in not less than three concentrations, preferably not less than five concentrations. By reacting a sufficient amount of the labeled external standard nucleic acid with this array and determining  
25

the amounts of the bound external standard nucleic acid, the ratio of the probe molecules actually immobilized on the DNA micro-array can be determined.

According to a third aspect of the present  
5 invention, there is provided a detection kit that makes a detection and determination method utilizing the DNA micro-array of the first or second aspect more efficient and easy.

The detection kit that uses a DNA micro-array  
10 having an internal standard probe comprises a primer set for the amplification of an internal standard nucleic acid. The detection kit using a DNA micro-array having an external standard probe includes an external standard nucleic acid labeled with a  
15 detectable and determinable marker and whose labeling rate has been determined. According to the internal standard probes or external standard probes, at least one, optionally several to ten or more primer sets or external standard nucleic acids are included in the  
20 detection kit.

The content of an primer set to amplify an internal standard nucleic acid varies depending on various requirements. First of all, the base sequences (position) of the primer set must be  
25 determined to produce an amplified product having a complementary base sequence to the internal standard probe in an amplification reaction using an internal

standard nucleic acid as a template. At the same time, care must be taken not to generate undesirable products by the amplification reaction using the target nucleic acid as a template. Further, in order 5 to improve accuracy as an internal standard, it should be avoided that the chain length of the amplified product of the target nucleic acid greatly differs from that of the internal standard amplified with the primer set in this kit. More specifically, 10 it is desired that the several amplified products differing in length are generated from the internal standard nucleic acid so that one of them is equal in length to the amplified product of the target nucleic acid. For example, four primer sets are prepared to 15 obtain four amplified products of 200 bp or less, 200 to 500 bp, 500 to 2,000 bp, and 2000 bp or more, so as to select one having the same chain length as the amplified product of the target nucleic acid. Of course, more primer sets may be prepared more finely 20 dividing the range of the chain length of the amplified products.

Preferable internal standard nucleic acid may be a nucleic acid of a known base sequence and high purity. Examples of such nucleic acid are 25 commercially available nucleic acids for molecular biological and medical use, such as plasmid vectors, phage DNA and microbial genomes. In particular,

plasmid vectors and phage DNA are preferred because they are available as a highly purified and homogeneous sample relatively easily.

On the other hand, the external standard  
5 nucleic acid labeled with a detectable and determinable marker with a known labeling rate may be also prepared using a nucleic acid having a known base sequence and of high purity such as synthetic DNA or a plasmid vector. Synthesized DNA is  
10 particularly preferred because of its stable labeling efficiency and high labeling rate per molecular weight.

Furthermore, the DNA micro-array of the present invention preferably has preferably both the internal  
15 standard probe and the external standard probe. In this case, the detection kit preferably includes the external standard nucleic acid as well as a primer set for the amplification of the internal standard nucleic acid.

20 As long as the external standard probe and the internal standard probe are treated separately, the same probes (sequence) can be used for them. When they are used at the same time, probes of different base sequences (different species) must be used  
25 because competition occurs between them. Density standard probes may serve as the external standard probes.

[Analyzing method using a density standard probe formed by the same method as the nucleic acid probe, added for assaying the amount or density of the  
5 nucleic acid probe]

The present invention further provides a method of analyzing a DNA array itself. The following embodiment is given to specifically illustrate the present invention.

10       Conventional quantitative analysis, for example, the analysis using TOF-SIMS has a problem that detected secondary ion intensity differs according to measurement conditions, namely, primary ion application conditions (acceleration energy, incident angle, ion species, and application amount) and secondary ion detection conditions (energy width), and when a sample is an insulator, elimination by an electron beam pulse-applied for the correction of charge and the degree of charge neutralization.  
15

20       In particular, when the sample is an insulator, charge conditions are not always the same between a standard sample and a sample to be measured when primary ions are applied to them. Therefore, to achieve a high level quantitativity, measurement  
25 conditions must be optimized precisely every time the sample is changed. When optimization is unsatisfactory, the accuracy of the measurement

results is not obtained. Creation of a calibration curve requires standard samples as many as the concentration levels to be measured, so that it requires a troublesome work.

5       When standard samples for a nucleic acid chip are prepared by spin coating as reported by P. Lazzeri et al., high density reproducibility can be obtained if averaged in a wide area, but uniformity of the coating is not necessary satisfactory in view  
10      of the minute area size of TOF-SIMS measurement as small as several tens to several hundreds  $\mu\text{m}^2$ , which gives a serious problem to the reliability of measurement results. To solve the above problem, the present invention provides a method for highly  
15      quantitative analysis of a so-called nucleic acid chip where a plurality of nucleic acids (probes) are arranged in a matrix pattern on a substrate, by using time-of-flight type secondary ion mass spectrometry (TOF-SIMS). The present invention also provides a  
20      DNA micro array which allows easy determination of the amount or density of nucleic acid of each probe dot arranged on the nucleic acid chip, by using TOF-SIMS.

The inventors of the present invention have  
25      conducted intensive studies to solve the above problem. They have found that when nucleic acid probe dots of known average fixation density as a

density standard and nucleic acid probe dots of unknown fixation density are formed by the same method on the surface of a substrate, and the density standard dots are subjected to the secondary ion mass spectrometry to detect secondary signals, it is possible to determine with highly reproducible quantitativity the nucleic acid concentration of probe dots of unknown concentration on a substrate by secondary ion mass spectrometry, on the basis of the signal intensity of the density standard dots.

Further, the DNA micro-array of this embodiment, can contain a probe of a single-stranded nucleic acid hybridized with a target nucleic acid on the substrate.

In addition, this embodiment provides a method of producing a DNA micro-array having nucleic acid probes having a plurality of nucleic acid-related substances arranged in a matrix pattern on a substrate, which comprises the step of forming nucleic acid probe dots of known average nucleic acid density per dot as density standards on part of the surface of a substrate on which the nucleic acid probe dots have been formed. In addition, this method comprises the steps of: forming nucleic acid probe dots in a matrix pattern on the substrate; and forming nucleic acid dots of known average nucleic acid density per dot as density standard on part of

the surface of the substrate, on which the nucleic acid probe dots have been already formed, by the same method with the probe dots. The DNA micro-array of this embodiment is characterized in that it has an  
5 area where dots of nucleic acid of known concentrations are arranged in addition to the nucleic acid probes arranged in a matrix pattern on the substrate. A calibration curve is generated based on the secondary ionic intensity by TOF-SIMS  
10 from that area, and then the amount of the nucleic acid probes (formed density) of a probe dot in another area on the DNA micro-array substrate is determined from its secondary ion intensity by using the calibration curve.

15 That is, in the DNA micro-array of this embodiment, dots of nucleic acid probe of which per dot density is known are formed on part of a substrate on which a plurality of nucleic acid-related substances are arranged in a matrix pattern  
20 (so-called DNA micro-array), and they are used as the density standard for quantitative measurement by TOF-SIMS. A calibration curve can be drawn instantly if nucleic acid probe dots being step-wisely different in concentration are formed on the DNA micro-array  
25 substrate, enabling more quantitative measurement. In general, the nucleic acid density per dot of the nucleic acid probe dots of known density is

separately determined by chemically analyzing probe dots prepared separately but in the same conditions.

The DNA micro-array of the present invention is generally produced by using a flat substrate of a  
5 size of 1 cm × 1 cm, 1 inch × 1 inch (25.4 mm × 25.4 mm) or of a slide glass size (for example, 26 mm × 76 mm) on which a matrix of probe dots are arranged. As described above, the present invention allows highly reliable TOF-SIMS determination of the density of the  
10 nucleic acid probe immobilized on respective dots arranged in a matrix pattern on the surface of a DNA micro-array, utilizing the above density standards formed on the same substrate.

In the DNA micro-array of this embodiment,  
15 nucleic acid probes arranged on the substrate are preferably immobilized on the substrate by covalent bonding as described later. For this purpose, it is effective to treat the surface of the substrate with (N-β-(aminoethyl)-γ-aminopropyltrimethoxysilane), a  
20 silane coupling agent having an amino group bonded thereto, and N-maleimidocaproyloxysuccinimido (EMCS), a crosslinking agent in order to form a coating film in the process of treating the surface of the substrate.

25 In chemical analysis for determining the amount of nucleic acid contained per dot, a plurality of DNA micro-arrays having a large number of nucleic acid

probe dots are prepared, by changing the nucleic acid concentration stepwise, and then these micro-arrays of a certain concentration are treated with an acid, for example, to separate the nucleic acid probes from 5 the substrate, and the total amount of the nucleic acid probes contained in this solution is determined separately by analyzing the trace amounts of phosphorus contained in the nucleic acid with microanalysis means. The microanalysis means used to 10 determine the trace amounts of phosphorus contained in the nucleic acid is not particularly limited but preferably one having high sensitivity and high accuracy, such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The detection limit of phosphorus by ICP- 15 MS is about 10 ppb. For determination, the amount of phosphorus must be at least 2 to 3 times as much as the above amount, that is, about 20 to 30 ppb. The minimum amount of a sample (amount of the solution) is 1 ml.

20 When nucleic acid probes are formed by an ink jet method described later, it is not difficult to form dots of nucleic acid probes in a matrix of 200 × 300, for example, in an area of 1 inch × 3 inch. By the ink jet method, the amount of one discharge is 25 highly reproducible and an average value thereof (order of pl) can be estimated with high reliability. The concentration of probe DNA (order of  $\mu$ M) in the

discharged solution used for the production of the above density standard dots is predetermined and of course known.

The total number of the nucleic acid probe dots  
5 to be solubilized for the substrates to obtain the sample amount required for the above ICP-MS can be estimated to a certain extent by using, in addition to the above values, the immobilized amount of the probe DNA (the amount obtained by subtracting the  
10 amount of probe DNA unimmobilized due to washing with water etc. from the discharged amount, a level of several tens of percents). More specifically, when a nucleic acid chip is produced under the above typical conditions, several tens of DNA micro-arrays having a  
15 matrix size of about 200 rows × 300 columns and a discharge rate per dot in the order of pl must be used for each concentration determination (order of  
μM).

As for dots formed as density standards on the  
20 DNA micro-array, the dot number of one known concentration is not particularly limited but it is preferable to form plural dots.

In this embodiment, the nucleic acid density of the probe dots of unknown density can be determined  
25 by using a calibration curve prepared from the signal intensities of secondary ions obtained from the nucleic acid probe dots changing the density stepwise.

In the analyzing method of the present invention, it is effective to use secondary ion intensity detected by the time-of-flight type secondary ion mass spectrometry for higher quantitativity.

5       The above secondary ion intensity is not a counting rate but preferably integrated intensity counted for a certain time under certain conditions. To be exact, the dose of the primary ion is preferably set to a certain value of  $1 \times 10^{12}/\text{cm}^2$  or  
10 less which is called "static conditions", and a count value of the following secondary ions released from a certain area is used as the secondary ion intensity. The dose of the primary ion must be not more than  $1 \times 10^{14}/\text{cm}^2$ .

15      Examples of the primary ion used for measurement by TOF-SIMS include  $\text{Cs}^+$  ion,  $\text{Ga}^+$  ion and  $\text{Ar}^+$  ion. Examples of the secondary ion species include  $\text{P}^-$ ,  $\text{PO}^-$ ,  $\text{PO}_2^-$  and  $\text{PO}_3^-$  derived from phosphate constituting the skeleton of a nucleic acid when the  
20 probe nucleic acid and the target nucleic acid introduced by hybridization are single-stranded nucleic acids, specifically DNA, RNA, cDNA (complementary DNA) or cRNA (complementary RNA). Detectable secondary ions are bases from which a  
25 proton has been eliminated, i.e.,  $\text{C}_5\text{H}_4\text{N}_5^-$  (134 a.m.u.) in case of adenine, in the case of guanine,  $\text{C}_5\text{H}_4\text{N}_5\text{O}^-$  (150 a.m.u.), in the case of cytosine,  $\text{C}_4\text{H}_4\text{N}_3\text{O}^-$  (110

a.m.u.) and in the case of thymine,  $C_5H_5N_2O_2^-$  (125 a.m.u.). When the nucleic acid probe is an RNA probe, the same secondary ion as the DNA probe can be detected except that  $C_4H_3N_2O_2^-$  (111 a.m.u.) derived from uracil can be detected in place of thymine.

When an insulating substrate such as a glass substrate is used as the substrate for the DNA micro-array, suitable application conditions must be determined for electron beam irradiation used in combination with primary ion beam irradiation in consideration of the pulse width and frequency of the primary ion, the dielectric constant of the sample and the thickness of the glass substrate.

The analyzing method of the DNA micro-array of the present invention is also characterized in that the secondary ion intensity derived from a nucleic acid can be quantitatively displayed as a 2-D image in accordance with the scanning using the primary ion application.

20

#### Examples

The following examples are provided for the purpose of further illustrating the present invention in more detail. These examples are just examples of the best embodiment according to the present invention but are in no way to be taken as limiting.

Example 1

<Preparation of internal standard nucleic acid>

A plasmid DNA of a known base sequence, pUC118 (3,162 bp, a product of Takara), was used as an 5 internal standard nucleic acid. To be a PCR template, the above plasmid pUC118 was cleaved by EcoRI restriction enzyme, in accordance with a predetermined method to prepare linear DNA. After confirming the condition of digestion by using 10 agarose gel electrophoresis, the reaction solution was treated with phenol, and the linear DNA of interest was collected by precipitation with ethanol. The collected linear DNA was dissolved in a TE buffer solution (10 mM Tris-HCl (pH of 7.5), 1 mM EDTA) to a 15 final concentration of 10 ng/ $\mu$ l (2.4 pmol/ml) to prepare a solution of internal standard nucleic acid.

Example 2

<Preparation of primers for the amplification of 20 internal standard nucleic acids>

As shown in Table 1 below, five forward primers P1 to P5 and four reverse primers RP1 to RP4 were selected as PCR primers on the basis of information on the base sequence of the linear pUC118 digested by 25 EcoRI prepared in Example 1.

Table 1

Name		Sequence	Chain length	Position	GC (%)
F-Primer	P1	gagacaataaccctgata	18	1083-1100	38.9
	P2	ccttaacgtgagtttcg	18	2101-2118	44.4
	P3	gcttggagcgaacgacct	18	2507-2524	61.1
	P4	gagtcgacacctgcaggcat	18	32-49	61.1
	P5	ggttggactcaagacgatag	20	2432-2451	50.0
R-Primer	RP1	taagttggtaaacgccag	18	116-99	50.0
	RP2	agggcgctggcaagtgtta	18	368-351	61.2
	RP3	cgttccggtatgacggt	18	926-909	55.6
	RP4	gcggtaatacggttatccac	20	2858-2839	50.0

(P1 to PR4: SEQ ID NO: 10 to SEQ ID NO: 18)

The positions of the primers shown in Table 1  
are those renumbered designating the first base of  
5 the EcoRI cleavage site as position 1. As for the  
reverse primers RP1 to RP4 in Table 1, the positions  
are on the complementary chain.

Each primer having a base sequence shown in  
Table 1 was synthesized and purified by high-  
10 performance liquid chromatography (HPLC) and  
dissolved in a TE buffer solution to a final  
concentration of 10 pmol/ $\mu$ l to prepare a primer  
solution.

Fig. 1 shows the chain lengths of amplified  
15 products obtained by carrying out PCR amplification  
reactions using primers shown in Table 1 and the  
internal standard nucleic acid (EcoRI-digested pUC118  
prepared in Example 1) as a template. Fig. 1 also  
shows combinations of forward primers and reverse  
20 primers used. Separately, 5'-fluorescent (rhodamine)

labeled reverse primers were prepared in the same manner as with the above unlabeled primers to prepare fluorescence-labeled primer solutions.

5 Example 3

<Preparation of internal standard probes>

Internal standard probes shown below were prepared based on the information on the base sequence of the linear plasmid DNA pUC118 EcoRI 10 digest prepared in Example 1.

Table 2

Name		Sequence	Chain length	Position	GC (%)
Probe	B-SH	actggccgtcggtttaca	18	61-78	50.0
	D-SH	gtgagctatgagaaaggcgcc	20	2549-2568	55.0
	F-SH	ggtatctttatagtcctgtc	20	2663-2682	40.0
	H-SH	ggcctttgctcacatgttc	20	2795-2814	50.0

(B-H: SEQ ID NO: 1 to SEQ ID NO: 4)

15 The positions of the probes shown in Table 2 are those renumbered designating the first base of the EcoRI cleavage site as position 1.

Four internal standard probes of which base sequences are shown in Table 2 were synthesized and 20 then a sulfanyl group was introduced to the 5' terminal of each nucleic acid as a functional group to immobilize the probes in the DNA micro-array in accordance with a conventional method. After the

introduction of the functional group, the internal standard probes were purified and freeze-dried. The freeze-dried internal standard probes were preserved in a freezer at -30°C.

5 Fig. 1 shows the positions of the target base sequence to which the four internal standard probes would hybridize. The position of each PCR product on the target base sequence is shown as well.

10 Example 4

<Preparation of external standard nucleic acids>

The following external standard nucleic acids were prepared based on information on the sequence of linear plasmid, pUC118 EcoR I Digest prepared in

15 Example 1.

Table 3

Name		Sequence	Chain length	Position	GC (%)
Target	A-Rho	tgtaaaacgacggccagt	18	78-61	50.0
	C-Rho	ggcgctttctcatagctcac	20	2568-2549	55.0
	E-Rho	gacaggactataaagatacc	20	2682-2663	40.0
	G-Rho	gaacatgtgagcaaaaggcc	20	2814-2795	50.0

(A-G: SEQ ID NO: 5 to SEQ ID NO: 8)

20 The positions of the probes shown in Table 3 are those renumbered designating the first base of the EcoRI cleavage site as position 1.

The four external standard nucleic acids are

complementary to the four internal standard probes shown in Table 2.

A fluorescent dye (rhodamine) was introduced to the 5' terminals of the four external standard nucleic acids of which base sequences are shown in Table 3 by a convention method after synthesis, as a marker for detection and quantification. After the introduction of the fluorescent marker, the external standard nucleic acids were purified and dissolved in a TE buffer solution to a final concentration of 5  $\mu\text{M}$  to prepare external standard nucleic acid solutions. The external standard nucleic acid solution were put in a light-shielded container and kept in a refrigerator at -30°C.

Fig. 1 shows the positions of the base sequences of the four external standard nucleic acids and the above four internal standard probes having complementary base sequences on the positions of the target base sequence.

20

#### Example 5

##### <Preparation of DNA micro-array>

###### [1] Cleaning of glass substrate

A synthetic quartz glass substrate (size: 25 mm  $\times$  75 mm  $\times$  1 mm, manufactured by Iiyama Tokushu Glass Co., Ltd.) was placed in a heat-resistant and alkali-resistant rack and immersed in a cleaning liquid of a

predetermined concentration for ultrasonic cleaning. After overnight immersion in the cleaning liquid, it was subjected to ultrasonic cleaning for 20 minutes. Subsequently, the substrate was taken out from the 5 cleaning liquid and lightly rinsed with pure water, and ultrasonic cleaning was carried out in ultra-pure water for 20 minutes. The substrate was then immersed in a 1 N sodium hydroxide aqueous solution at 80°C for 10 minutes. After washing with pure 10 water and with ultra-pure water, a cleaned quartz glass substrate for a DNA chip was obtained.

## [2] Surface treatment

A silane coupling agent (KBM-603, a product of Shin-Etsu Silicone Co., Ltd.) was dissolved in pure 15 water to a concentration of 1 wt% and stirred at room temperature for 2 hours. Subsequently, the cleaned glass substrate was immersed in the aqueous solution of the silane coupling agent and kept at room temperature for 20 minutes. Then the glass substrate 20 was pulled up, lightly washed with pure water on both surfaces, and dried by blowing nitrogen gas onto both sides. The dried substrate was then baked in an oven heated at 120°C for 1 hour to complete the coupling treatment, thereby amino groups were introduced onto 25 the surface of the substrate.

Next, N-(6-maleimidocaproyloxy)succimido (EMCS) (a product of by Dojin Kagaku Kenkyujo Co.,

Ltd.) was dissolved in a solvent mixture of dimethyl sulfoxide and ethanol (volume ratio of 1:1) to a final concentration of 0.3 mg/ml to prepare an EMCS solution. The glass substrate baked and cooled was  
5 then immersed in the EMCS solution at room temperature for 2 hours. By this treatment, maleimido groups were introduced onto the substrate surface through the reaction between the succimido group of EMCS and the amino groups on the substrate  
10 surface introduced by the silane coupling agent treatment. Then the glass substrate was pulled up from the EMCS solution and washed with the above mixed solvent of dimethyl sulfoxide and ethanol. After further washing with ethanol, the surface-  
15 treated glass substrate was dried in a nitrogen gas atmosphere.

[3] Probe DNA

The four internal standard probes prepared in Example 3 were dissolved in pure water to prepare  
20 solutions of various concentrations and compositions as shown in Table 4 below. Each internal standard probe solution was divided into aliquots and freeze-dried to remove water.

Table 4

No.	Component	Concentration
1	B-SH	1.50 D/ml
2	D-SH	
3	F-SH	
4	H-SH	
5	B-SH	0.750 D/ml
6	D-SH	
7	F-SH	
8	H-SH	
9	B-SH	0.50 D/ml
10	D-SH	
11	F-SH	
12	H-SH	
13	B=SH	0.3750 D/ml each
14	D-SH	
15	F-SH	
16	H-SH	
17	B+D	Mixture of two probes
18	B+F	
19	B+H	
20	D+F	
21	D+H	
22	F+H	
23	B+D+F	Mixture of three probes
24	B+D+H	
25	B+F+H	
26	D+F+H	Mixture of four probes
27	B+D+F+H	

[4] Discharge of DNA by BJ printer and bonding to substrate

5 An aqueous solution containing 7.5 wt% of glycerin, 7.5 wt% of thiodiglycol, 7.5 wt% of urea and 1.0 wt% of Acetylenol EH (produced by Kawaken Fine Chemical Co., Ltd.) was prepared. Then, an aliquot of each of 27 freeze-dried probe solutions

shown in Table 4 was dissolved in a specific amount of the above mixed solvent to a specific concentration. The obtained DNA probe solutions were respectively charged into ink tanks for a bubble jet 5 printer (trade name: BJF-850, manufactured by Canon Inc.), and the tank was mounted to a printing head.

The bubble jet printer used herein was modified to enable printing on a plane surface. This bubble jet printer can discharge ink droplets according to a 10 pattern inputted using a certain file creation method, and can spot about 5 pico liter of the DNA solution at a pitch of about 120  $\mu\text{m}$ .

Subsequently, the 27 different probe solutions were spotted onto a surface-treated glass substrate, 15 in accordance with the order shown in Fig. 2, using the above modified bubble jet printer. After confirming that intended spotting was carried out, the glass substrate was left to stand in a humidified chamber for 30 minutes to react the maleimido groups 20 on the surface of the glass substrate with the sulfanyl groups at the 5' terminals of the DNA probes.

#### [5] Washing

After 30 minutes of reaction, the DNA solutions remaining on the surface were washed away with a 10 25 mM phosphate buffer solution (pH of 7.0) containing 100 mM NaCl to obtain a gene chip (DNA probe array substrate) having immobilized single-stranded DNAs

spotted in a matrix pattern on the surface of the glass substrate.

Example 6

5 <Calibration of substrate using external standard nucleic acid>

Eight DNA micro-arrays prepared in Example 5 were used. The eight DNA micro-arrays were immersed in a blocking solution having a composition shown  
10 below and left to stand at room temperature for 3 hours to carry out blocking treatment.

Table 5

Composition of blocking solution

Component	Content
Bovine serum albumin (produced by Sigma Co., Ltd.)	2% (w/v)
NaCl	100 mM
Phosphate buffer solution pH 7.0	10 mM

15

Meanwhile eight different hybridization solutions containing external standard nucleic acid as shown in Table 6 were prepared. The basic solvent for these hybridization solutions was a 10 mM phosphate buffer solution (pH of 7.0) containing 100 mM NaCl (to be referred to as "basic buffer solution" hereinafter), and each of the external standard nucleic acids shown in Table 6 or a mixture thereof was dissolved in this basic buffer solution to a

total nucleic acid concentration of 30 nM.

Table 6

No.	External standard nucleic acid	Content
1	A	30 nM each
2	G	30 nM each
3	A+G	15 nM each
4	C+G	15 nM each
5	E+G	15 nM each
6	A+C+G	10 nM each
7	C+E+G	10 nM each
8	A+C+E+G	7.5 nM each

5        In Table 6, abbreviations in the column of external standard nucleic acids designate the external standard nucleic acids shown in Table 3, indicating that corresponding external standard nucleic acids are contained.

10      DNA micro-arrays subjected to the blocking treatment and rinsed with the basic buffer solution were immersed in the eight hybridization solutions respectively and sealed up in a vinyl pack. A hybridization reaction was carried out in each DNA 15      micro-array at 45°C for 3 hours.

After the completion of the reaction, each DNA micro-array was taken out from the vinyl pack and the following cleaning was carried out.

The DNA micro-array was washed with 2 × SSC + 20      0.1 % sodium dodecylsulfate (SDS) at 55°C for 5

minutes for three times and 0.1 × SCC at room temperature for 1 minute once. The composition of 2 × SSC was: NaCl 17.5 g/l, trisodium citrate·dihydrate 8.8 g/l, adjusted to pH 7.0 with sodium hydroxide.

5        After washing, extra liquid was blown off with air to dry the DNA micro-array. After drying, the fluorescence intensity at each spot was measured by using a DNA array scanner (GenePix 4000B, manufactured by Axon Co., Ltd.). The measurement  
10      data was analyzed by using analytical software (Genepix Pro 3.0) attached to the DNA array scanner.

Example 7

<Density calibration of immobilized probes>

15       The density ratio of the probes was calculated from the measured fluorescence intensities. The results are shown in Table 7.

Table 7

No.	Content		Concentration	Density ratio (%)
1	B-SH	One kind	1.50 D/ml	185
2	D-SH			189
3	F-SH			187
4	H-SH			189
5	B-SH	One kind	0.750 D/ml	100
6	D-SH			100
7	F-SH			98
8	H-SH			101
9	B-SH	One kind	0.50 D/ml each	67
10	D-SH			66
11	F-SH			66
12	H-SH			68
13	B-SH	One kind	0.3750 D/ml each	51
14	D-SH			49
15	F-SH			51
16	H-SH			50

The density ratio was calculated as a relative ratio making the immobilization density of the DNA probe of Ink No. 5 to 100 %. The density ratios shown in Table 7 were determined by first determining the labeling rate of each external standard nucleic acid separately and then correcting the density ratio with the labeling rate.

In Table 7, the density ratios of Ink Nos. 1 to 4 (amounts of fluorescence) do not reach the theoretical value of 200 %, because the immobilized amount of the probe nucleic acid reached the permissible amount (saturation amount) of the substrate.

The density ratio of each probe in the mixed probe ink Nos. 17 to 27 shown in Table 4 was similar to the density ratio of the corresponding single probe of a corresponding concentration.

5

Example 8

<Creation of calibration curve using external standard nucleic acid>

The amount of each probe immobilized was  
10 measured from the results of Example 7 and a calibration curve was drawn using the correction data.

More specifically, hybridization experiments were conducted in the same manner as in Example 6 using the DNA micro-array prepared in Example 5. The 15 external standard nucleic acid was added as a mixture in amounts shown below.

Mixing ratio of the external standard nucleic acids:  
A-Rho: 66.7 % (20 nM)  
C-Rho: 25.0 % (7.5 nM)  
20 E-Rho: 6.7 % (2.0 nM)  
G-Rho: 1.7 % (0.5 nM)

The measurement and analysis were carried out in the same manner as in Example 6.

Calibration curves were drawn using the 25 measurement results and the correction values of probe density obtained in Example 7. Fig. 3 shows the obtained calibration curves.

Example 9

<Creation of calibration curves using PCR products>

Calibration curves of PCR amplified products were drawn using the internal standard nucleic acid 5 prepared in Example 1 and the internal standard primers prepared in Example 2.

First, a PCR amplification reaction was carried out using a combination of internal standard primers shown in Table 8 in accordance with a predetermined 10 method. The composition of a PCR reaction solution is as follows. The reverse primers used in this example were primers whose 5' terminals were labeled with fluorescence prepared in Example 3.

-PCR reaction solution-

15	PCR premix reaction solution (2x)	25 µl
	pUC118 EcoR I Digest	1 µl
	Mixed primer (Table 8)	6 µl
	Pure water	18 µl/50 µl in total
	Temperature cycle (24 cycles each including: 92°C for 20 sec; 62°C for 15 sec; and 72°C for 30 sec)	

Table 8

No.	Forward primer	Reverse primer	Primer concentration	Chain length of amplified product	
1	P-4	PR-2*	5 nmol/ml each	337 bp	
2		PR-3*		895 bp	
3	P-1	PR-4*		1776 bp	
4	P-2			758 bp	

\* labeled with fluorescence.

After the reaction, gel filtration was carried to purify the PCR amplified product. A TE buffer solution was used to adjust the volume of the PCR amplified product, and then the absorbance at 240 nm 5 and the amount of fluorescence were measured to determine the amount of nucleic acid and the amount of the product labeled by fluorescence in order to obtain the labeling rate.

A hybridization reaction was carried out in the 10 same manner as in Example 8 using the internal standard amplified product of known labeling rate to measure the amount of fluorescence derived from the internal standard amplified product bounding to the probe.

15 Calibration curves were drawn from the measurement results using the labeling rate of the internal standard amplified product and the correction value of probe density obtained in Example 7. Fig. 4 shows the obtained calibration curves.

20 When the calibration curves shown in Fig. 4 are reviewed, there is a difference in the slope between the calibration curves depending on the molecular weight (chain length) of the amplified products. That is, in order to determine the target nucleic 25 acid with higher reliability, it is necessary to employ a combination of primers giving internal standard amplified products having the same chain

length as the amplified product of the target nucleic acid.

The following examples show use of density standard probes formed by the same method as with the 5 nucleic acid probes to determine the amount or density of the above nucleic acid probes.

Example 10

Fig. 5 schematically shows the plane 10 arrangement of an array of probe spots bonded to a substrate and the sectional structure of the probe array. Reference numeral 501 denotes a group of probes prepared under arbitrary conditions; and 502, a group of probes having a known nucleic acid 15 concentration. In the sectional view, reference numeral 503 denotes a substrate; 504, a surface-treated layer made from an organic material; and 500, a nucleic acid probe. The process for producing this probe array shown in Fig. 5 using a known method 20 (method 9 disclosed in JP H11-187900 A) will be described hereinbelow.

The cleaning [1] and surface treatment [2] of the glass substrate were carried out in the same manner as in Example 5.

25 [3] Synthesis of probe DNA

Single-stranded nucleic acid having SEQ ID NO: 9 (40-mer of dT) was synthesized by a DNA

manufacturer (Bex Co., Ltd.). A (SH) group was introduced into the 5' terminal of the single-stranded DNA having SEQ ID NO: 1 by using a thiol modifier (Glen Research Co., Ltd.). After the DNA synthesis, deprotection and the collection of DNA were carried out by conventional methods and HPLC was used for purification. The manufacturer did the steps from synthesis to purification.

SEQ ID NO: 9  
10 5' HS-(CH<sub>2</sub>)<sub>6</sub>-O-PO<sub>2</sub>-O-TTTTTTTTT TTTTTTTTT TTTTTTTTT  
TTTTTTTTT 3'

[4] Discharge by thermal jet printer and bonding of DNA to substrate

A single-stranded DNA of SEQ ID NO: 1 described in [3] was dissolved in a solution containing 7.5 wt% of glycerin, 7.5 wt% of urea, 7.5 wt% of thioglycol and 1 wt% of acetylene alcohol (trade name: Acetylenol EH; produced by Kawaken Fine Chemical Co., Ltd.) to a final concentration of 8 μM.

20 The BC-50 printer head (manufactured by Canon Inc.) for the BJF-850 bubble jet printer (manufactured by Canon Inc.) using a bubble jet method (a kind of thermal jet method) was modified to discharge several hundreds μl of a solution. This 25 modified head was mounted to a modified discharge-drawing machine so that ink could be discharged to a flat quartz substrate. The above DNA solution was

injected in the modified tank of this head in an amount of several hundred  $\mu\text{l}$  and the EMCS-treated substrate was set in the drawing machine to spot the solution on the EMCS-treated surface. The discharge 5 amount of the solution at one ejection was 4  $\mu\text{l/droplet}$  and the spotted area was 20 mm  $\times$  30 mm on the substrate at a pitch of 200 dpi, that is, 127  $\mu\text{m}$  intervals. Under the above conditions, the diameter of dots spotted in a 157  $\times$  236 matrix pattern (157 10 rows, 236 columns) was about 50  $\mu\text{m}$ .

After spotting, the substrate was left to stand in a humidified chamber for 30 minutes for reaction of the maleimido group on the surface of the substrate and the sulfanyl group (-SH) at the 5' terminals of 15 the nucleic acid probes in order to immobilize the DNA probes. Thereafter, the substrate was rinsed with pure water and preserved in pure water. Just before TOF-SIMS analysis, the DNA bonded substrate (DNA chip) was dried by blowing nitrogen gas and 20 further dried in a vacuum desiccator. Under the above conditions, 15 DNA chips were produced in total.

Further, 25 DNA chips and 35 DNA chips were prepared by the same manner as above except that the concentration of the above single-stranded DNA (SEQ 25 ID NO: 1) in the spotting solution was changed to 5  $\mu\text{M}$  and 2.5  $\mu\text{M}$  respectively. The above three types of DNA chips were designated as standard DNA chips.

Thereafter, a DNA chip was produced under the same conditions as above using a single-stranded DNA solution of an ordinary concentration (about 8  $\mu\text{M}$ ). In the above DNA chip, the first to third rows from 5 the end thereof were formed respectively using the same three single-stranded DNA solutions as used in the preparation of the standard DNA chips. That is, probe spots were formed with the DNA solution having a concentration of 10  $\mu\text{M}$  in the first row at the 10 endmost position of the substrate, probe spots were formed with the DNA solution having a concentration of 5  $\mu\text{M}$  in the second row, and probe spots were formed with the DNA solution having a concentration of 2.5  $\mu\text{M}$  in the third row. The other rows (4th to 15 157th rows) were formed with a 8  $\mu\text{M}$  solution of DNA of another lot. The number of probe arrays can be set to any value.

Example 11  
20 <Determination of nucleic acid on nucleic acid chip>  
The standard DNA chips produced in three different DNA concentrations were washed with an acid to dissolve DNA probes and the solution was concentrated to 1 ml or less under conditions that 25 the acid solution did not scatter. Thereafter, ultra-pure water was added to the concentrated solution to a total volume of 1 ml. This solution

was introduced into an ICP-MS apparatus to measure the mass of P (phosphorus). Based on this measurement value, in consideration of the number of dots used for the above measurement (number of spots),  
5 the average value of the number of DNA molecules per dot was determined for each DNA concentration. The number of substrates of each DNA concentration may be determined in consideration of the detection limit concentration of P of the ICP-MS apparatus (about 10  
10 ppb) and the number of DNA molecules on the substrate, not limited to the number of substrates in Example 10.

Example 12

<TOF-SIMS measurement>

15       The DNA chip shown in Fig. 5 was conveyed to the analysis chamber of a time-of-flight type secondary ion mass spectrometer (TOFSIMS IV: manufactured by ION TOF Co., Ltd.) and irradiated with ions to the final primary ion dose density of 1  
20       $\times 10^{12}$  atoms/cm<sup>2</sup> under conditions shown in Table 1. The secondary ion PO<sub>3</sub><sup>-</sup> (mass charge ratio of 78.958 amu (atom mass unit)) detected during this operation was integrated to obtain cumulative intensity. Fig. 6 shows a relationship between the average value of  
25      secondary ion intensity of the dots of one DNA concentration formed on one of the first to third rows and the DNA formation density (number of DNA

molecules per dot). The intensity of  $\text{PO}_3^-$  measured with the surface-treated substrate right before the probe DNA immobilization was used as the background.

It was confirmed that the DNA formation density  
5 and the secondary ion intensity of the dots of each  
row were in proportion. When TOF-SIMS analysis was  
carried out under the same measurement conditions for  
a nucleic acid probe array prepared using a  $8\mu\text{M}$   
nucleic acid solution and an ink jet printer to  
10 discharge the solution, the DNA formation density of  
each dot (number of DNA molecules per dot) obtained  
from a count value of  $\text{PO}_3^-$  was about  $2.0 \times 10^7$  and the  
variation in 10 dots selected at random was 20 % or  
less.

15

Table 9 Measurement conditions of TOF-SIMS

Primary ion		Secondary ion	
Ion species	$\text{Ga}^+$	Ion species	$\text{PO}_3^-$
Acceleration voltage	25 kV	Measurement area	$300\mu\text{m} \times 300\mu\text{m}$
Pulse	2.5 kHz	Integrating circuit	256

Example 13

<Imaging of formation density distribution>

20 The same nucleic acid probe array as in Example  
12 was prepared, and its surface was scanned with  
primary ions to display the generated secondary ions  
corresponding to each scan point, the intensity of  $\text{P}^-$   
obtained at each scanning point was classified into a

plurality of intensity levels, and a dummy color was set for each level to quantitatively compare the intensity distribution of P<sup>-</sup>, that is, the distribution of surface density or formation density 5 of nucleic acid (number of molecules of nucleic acid per probe dot).

As described above, according to the present invention, provided is a DNA micro-array which enables easy and detailed analysis. More 10 specifically, detection of a nucleic acid which is the actual object and an assay work can be carried out concomitantly. Highly accurate assay results can be obtained because quantitative assay is carried out simultaneously with the detection operation.

15 Therefore, the determination accuracy of the quantitative analysis of the molecules of a target nucleic acid is greatly improved by using the DNA micro-array according to the present invention. For quantitative analysis, internal standard 20 amplification primers and external standard nucleic acids are used as a detection kit in accordance with the DNA micro-array according to the present invention so that a user can make use of the present invention very easily. Further, nucleic acid probe 25 dots for use as density standards whose average nucleic acid density per dot has been determined and which are formed by the same method as the formation

of the above nucleic acid probe dots are existent on the chip substrate, whereby the nucleic acid concentrations of nucleic acid probe dots having an unknown concentration arranged on the substrate can

5 be determined by secondary ion mass spectrometry.

Therefore, reproducibility and quantitativity are improved as compared with the prior art method.

Using the method of the present invention, the reliability of DNA micro-array products can be

10 improved. It also enables to visualize the density distribution of nucleic acid probe dots formed in a matrix pattern in the DNA micro-array.